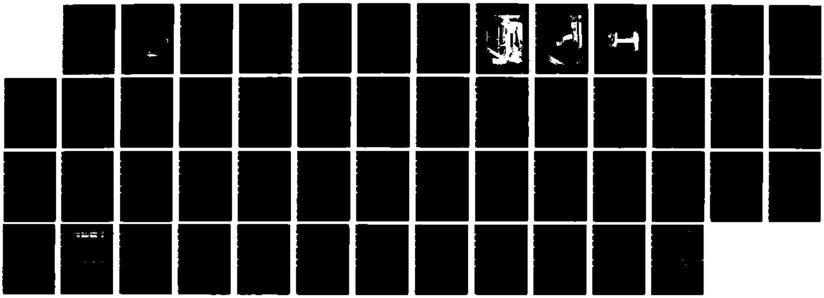
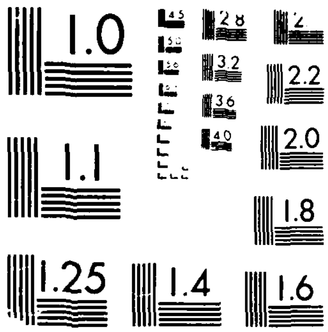
AD-A190 674 PRELIMINARY AIRWORTHINESS EVALUATION OF THE UH-60A WITH ADVANCED DIGITAL (U) ARMY AVIATION ENGINEERING FLIGHT ACTIVITY EDWARDS AFB CA G L BENDER ET AL AUG 87 1/1

UNCLASSIFIED F/G 1/4 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

②

AEFA PROJECT NO. 86-05

US ARMY
AVIATION
SYSTEMS COMMAND

AD-A190 674

PRELIMINARY AIRWORTHINESS EVALUATION OF THE UH-60A WITH ADVANCED DIGITAL OPTICAL CONTROL SYSTEM (ADOCS)

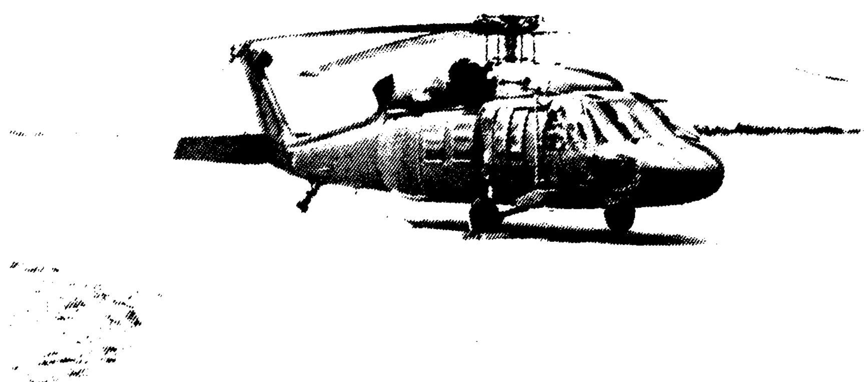
GARY L. BENDER
PROJECT OFFICER/ENGINEER

ROBERT D. ROBBINS
PROJECT PILOT

AEFA

AUGUST 1987

FINAL REPORT



Approved for public release; distribution unlimited.

AVIATION ENGINEERING FLIGHT ACTIVITY
EDWARDS AIR FORCE BASE, CALIFORNIA 93523 - 5000

88 2 11 011

DISCLAIMER NOTICE

DISPOSITION INSTRUCTIONS

TRADE NAMES

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS A190 674
2a. SECURITY CLASSIFICATION AUTHORITY U.S. ARMY AVIATION SYSTEMS COMMAND	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release, distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AEFA PROJECT NO. 86-05	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. ARMY AVIATION ENGINEERING FLIGHT ACTIVITY 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) EDWARDS AIR FORCE BASE, CALIFORNIA 93523-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. ARMY AVIATION SYSTEMS COMMAND 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) 4300 GOODFELLOW BLVD. ST. LOUIS, MO 63120-1998	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO.: EK-7PW712-EK-EC PROJECT NO.: TASK NO: WORK UNIT ACCESSION NO.:

11. TITLE (Include Security Classification)
Preliminary Airworthiness Evaluation of the UH-60A with Advanced Digital Optical Control System (ADOCS). Unclassified

12. PERSONAL AUTHOR(S)
Gary L. Bender, Robert D. Robbins

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
FINAL	FROM 87/03 TO 87/04/9	87/08	52

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Advanced Digital Optical Control System (ADOCS), Handling Qualities, Limited-Displacement Side-Arm Controllers, Preliminary Airwortiness Evaluation, UH-60 Helicopter

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The Advanced Digital Optical Control System (ADOCS) is being developed on a UH-60A helicopter by the Boeing Vertol Company (BV) under a contract with the U.S. Army Aviation Applied Technology Directorate (AATD) of the U.S. Army Aviation Research and Technology Activity of the U.S. Army Aviation Systems Command to demonstrate the feasibility of a digital optical control system. The U.S. Army Aviation Engineering Flight Activity conducted a Preliminary Airworthiness Evaluation of ADOCS installed on a UH-60A aircraft to evaluate the handling qualities and to provide data for issuance of an airworthiness release for an AATD demonstration of the system to the army aviation community through a guest pilot program. The ADOCS consists of a Primary Flight Control System, which incorporates limited-displacement side-arm controllers for pilot inputs (right-side pilot station only), and an Automatic Flight Control System (AFCS) which is used to augment the basic UH-60A stability. Displacement of the controllers is measured and transmitted optically to digital flight control processors where the control commands are summed with the AFCS commands and sent to the rotor control

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL SHEILA R. LEWIS	22b. TELEPHONE (Include Area Code) (805)277-4024 22c. OFFICE SYMBOL SAVTE-PR

DD Form 1473, JUN 86 Previous editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

Block No. 19

actuators. The evaluation was conducted at the BV Flight Test Center at Wilmington, Delaware between 25 March and 9 April, 1987 and consisted of 9 flights comprising 17.5 hours (14.9 productive hours). Tests included handling qualities, simulated system failures, and mission maneuvers. Three enhancing characteristics were found: (1) the ease in rolling to and maintaining a desired bank angle; (2) the capability to maintain "hands-off" stabilized hover with all selectable modes engaged, and; (3) the capability of the barometric altitude hold mode to maintain altitude during simulated instrument flight tasks. Additionally, no deficiencies and 19 shortcomings were found. The safety, performance, and reliability of the ADOCS were found to be adequate to proceed to a user demonstration. Additionally, the scope of the BV user demonstration flight plan was found to be satisfactory.

TABLE OF CONTENTS

INTRODUCTION

BACKGROUND

1. The Advanced Digital Optical Control System (ADOCS) is being developed on a UH-60A helicopter by the Boeing Vertol Company (BV) under a contract with the US Army Aviation Applied Technology Directorate (AATD) of the U.S. Army Aviation Research and Technology Activity of the US Army Aviation Systems Command (AVSCOM). The ADOCS is being developed to demonstrate the feasibility of a digital optical control system on a helicopter. The AATD plans to demonstrate the system to the army aviation community through a guest pilot (or user demonstration) program. The AVSCOM requested (ref 1, app A) the US Army Aviation Engineering Flight Activity (AEFA) to conduct a preliminary airworthiness evaluation (PAE) of the ADOCS installed on a UH-60A aircraft to provide data for issuance of an airworthiness release for the guest pilot program.

TEST OBJECTIVES

2. The objective of this PAE was to conduct a qualitative and quantitative handling qualities evaluation of the UH-60A/ADOCS test aircraft to substantiate issuance of an airworthiness release for user demonstration.

DESCRIPTION

3. The test aircraft is a UH-60A modified to accept the ADOCS. The UH-60A is a single-main-rotor, dual-engine, utility helicopter and is described in the Operator's Manual (ref 2, app A). The ADOCS consists of a primary flight control system (PFCS), and a four-axis automatic flight control system (AFCS) which is used to augment the basic UH-60A stability. The ADOCS AFCS is a completely separate system from the basic UH-60A AFCS. The ADOCS pilot station is shown in photo 1. The ADOCS incorporates limited-displacement controllers for pilot inputs (right-side pilot station only). Displacement of these controllers by pilot commands is measured and transmitted optically to digital flight control processors. The flight control processors shape the control inputs, sum them with the AFCS commands and send optical signals to control the main and tail rotor actuators. For this evaluation, a right-hand, three-axis, side-arm controller was used for longitudinal, lateral and directional inputs (photo 2), and a left-hand, side-arm collective control (photo 3) was used. Both optical and electronic sensors were added to the UH-60 to measure aircraft state variables and actuator positions. The ADOCS also used the standard UH-60 doppler and radar altimeter. The output of

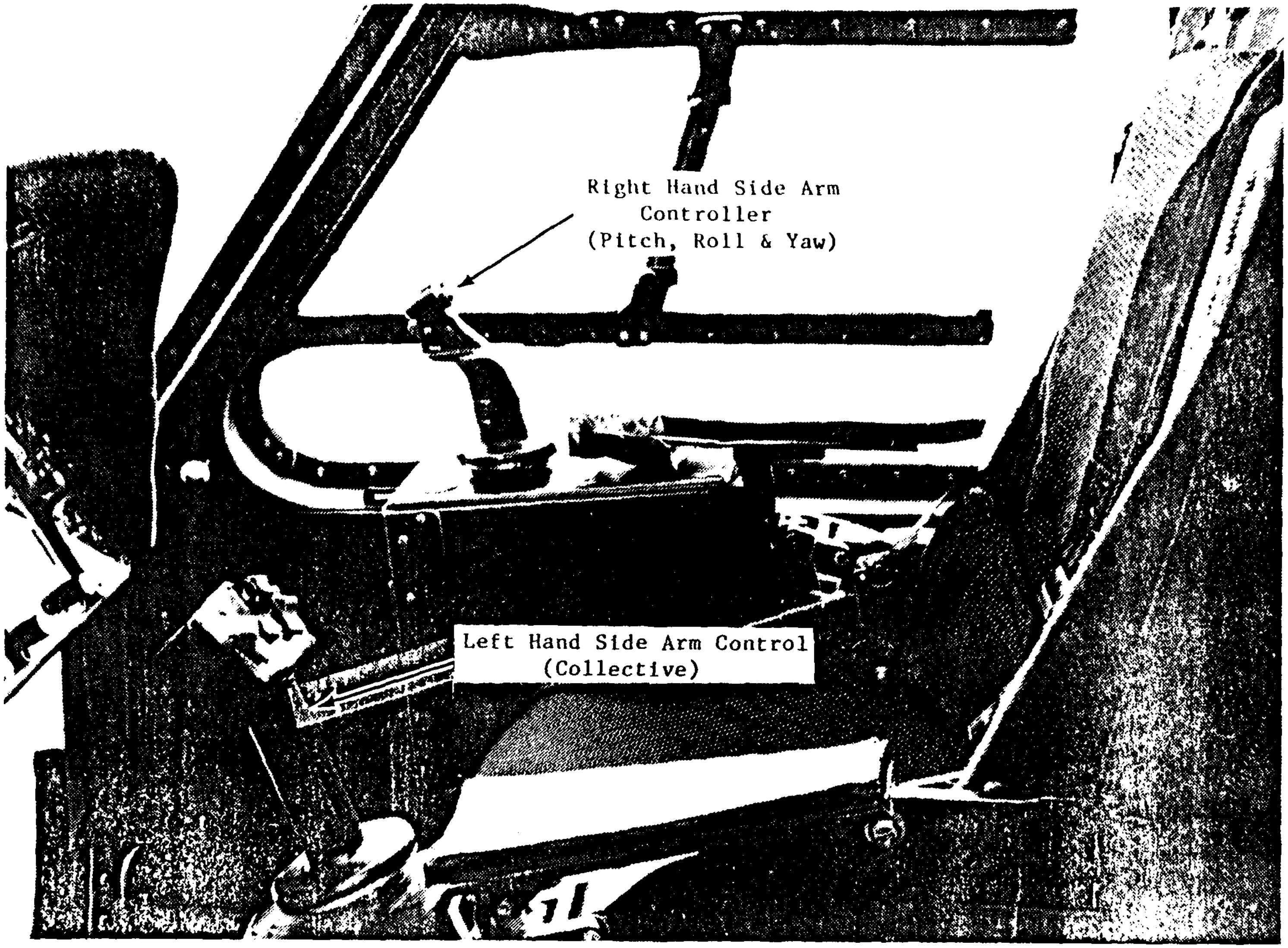


Photo 1. ADOCS Pilot's Station

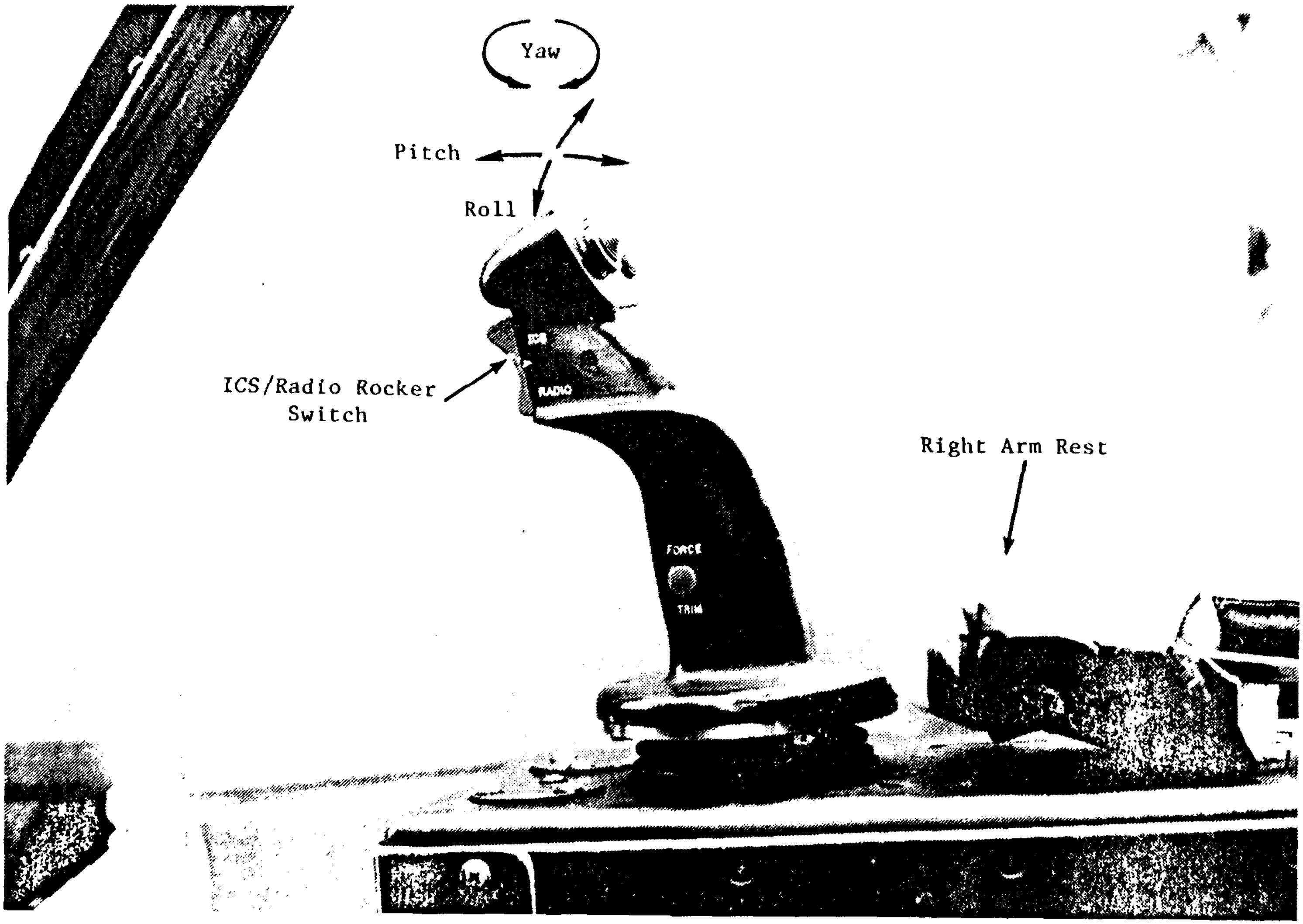


Photo 2. ADOCS Right Hand Side Arm Controller

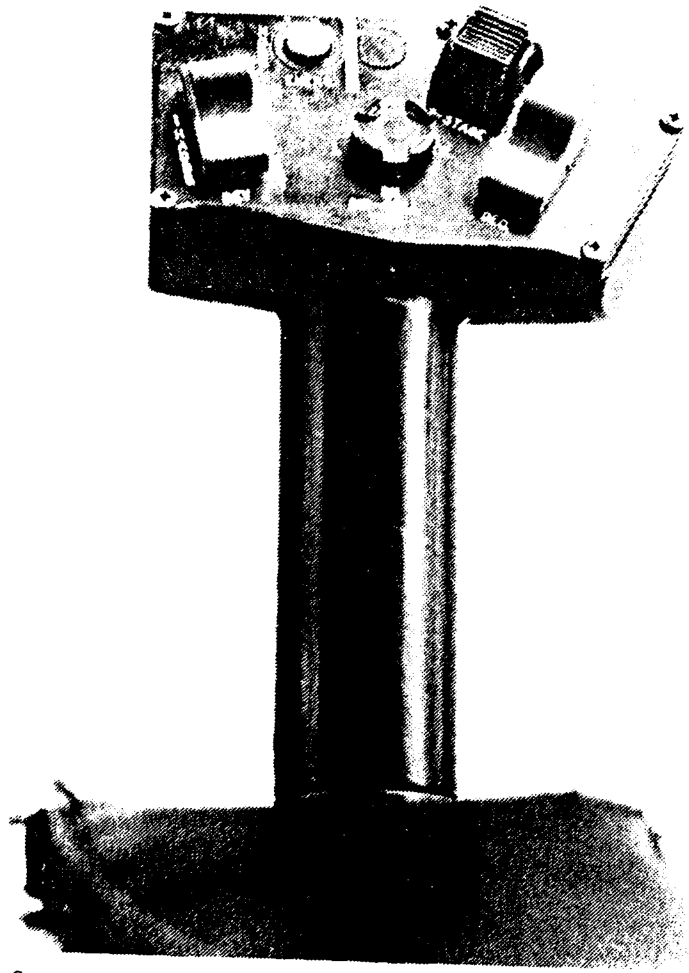


Photo 3. ADOCS Left Hand Side Arm Collective Control

these sensors was transmitted either electrically or optically to the PFCS and ADOCS AFCS processors. A unique feature of the ADOCS is that the PFCS and AFCS processors are separate and therefore the augmented aircraft stability and controllability can be changed independently. The left-side pilot station incorporates the standard UH-60A pilot controls, which are back-driven to follow the total control commands sent to the rotors and are used as a safety backup control system (BUCS). The ADOCS is equipped with a software monitor which will disengage both the PFCS and AFCS if any of a number of limits are exceeded (called a monitor trip). A further description of the ADOCS system is contained in appendix B.

TEST SCOPE

4. A preliminary airworthiness evaluation of the ADOCS-equipped UH-60A helicopter was conducted at the BV Flight Test Center at Wilmington, Delaware. The evaluation consisted of 9 flights comprising 17.5 hours (14.9 productive hours) and was conducted between 25 March and 9 April, 1987. After the first five flights, modifications to the flight control system software were made and many of the tests were reflown. Results discussed in this report pertain only to the second set of software, which will be used for the user demonstration (see app B for software designation). BV was responsible for aircraft maintenance, instrumentation installation and maintenance, and data processing. Additionally, BV provided a safety pilot to fly in the left seat during all tests. The tests were conducted using the limits and procedures of the airworthiness release (ref 3, app A), the operator's manual (ref 2), and the ADOCS checklist. Tests conducted and test conditions are listed in table 1.

TEST METHODOLOGY

5. The handling qualities of the aircraft were evaluated with various control system modes selected. The effectiveness of the modes, as well as control system transients resulting from selecting or deselecting the modes were evaluated. The capability for the BUCS safety pilot to safely disengage the ADOCS system and resume control of the aircraft was also checked in all flight regimes. Flight test data were obtained from calibrated test instrumentation and were recorded on magnetic tape. Real time telemetry was used to monitor selected parameters throughout the test. A detailed listing of the test instrumentation is contained in appendix C. Test techniques and data analysis methods are described in appendix D. The Handling Qualities Rating Scale (HQRS) shown in appendix D was used to quantify pilot comments.

Table 1. Test Conditions[1]

Test	Pressure Altitude (feet)	Selectable Mode Status: Heading Hold	Altitude Hold	Velocity Stability	Hover Assist	Indicated Airspeed (knots)	Flight Conditions	Remarks
Control Transfers	Field[2]	ON/OFF	OFF	OFF	OFF	0	Ground	BUCS[4] to DOCS[5] and DOCS to BUCS
	5000	ON/OFF	BARO[3] & OFF	OFF	OFF	50 & 120	Level	
	5000	ON	OFF	OFF	OFF	120	IRP[6] Climb & Auto Descent	
	20 ft AGL[7]	ON/OFF	RAD[8] & OFF	ON/OFF	ON/OFF	0	Hover	
Trimmed Forward Flight	5000	ON	BARO & OFF	OFF	OFF	40 to 150	Level	AFCS[9] ON & OFF
	100 FT AGL	ON	RAD	ON	ON	0 to 120	Level	
Turning Flight	5000	ON	BARO & OFF	OFF	OFF	80, 100 120, 150	Turns & Roll Reversals	Left & Right
	100 FT AGL	ON	OFF	ON/OFF	OFF	0 to 70 70 to 0	Turning Acceleration Turning Deceleration	
	20 FT AGL	ON	RAD	ON	ON	0	Hover Turn	
Dynamic Stability and Controllability	5000	ON/OFF	BARO & OFF	OFF	OFF	50 & 120	Level	Steps and pulses in all four axes
	50 FT AGL	ON/OFF	RAD & OFF	ON/OFF	ON/OFF	0	Hover	
Climbs and Descents	5000	ON	OFF	OFF	OFF	40 to 120	IRP Climb & Auto Descent	
	5000	ON	BARO	OFF	OFF	100	IRP Climb to Auto Descent	Increments of 500 fpm
	600 ft to 200 ft AGL	ON	RAD	ON	ON	0	Climb & Descent	
		ON	BARO	OFF	OFF	80		
Takeoff and Landing Characteristics	Field	ON/OFF	RAD & OFF	ON/OFF	ON/OFF	0		Vertical takeoff & landing
		ON	OFF	ON	OFF	30		Rolling takeoff & landing
		ON	OFF	OFF	OFF	0	Inclined surface	8 deg left side up 8 deg right side up 5 deg nose up 5 deg nose down
Low Speed Flight Characteristics	20 ft AGL	ON	RAD & OFF	ON/OFF	ON/OFF	0 TO 60 0 TO 40	Forward, Rearward, Sideward	AFCS ON & Off
AFCS Failures	5000	ON	BARO & OFF	OFF	OFF	80, 100	Level	
	20 ft AGL	ON	RAD & OFF	ON/OFF	ON/OFF	0	Hover	
	5000	ON	BARO	OFF	OFF	100	Turn	Steady & Rolling
		ON	OFF	OFF	OFF	100	Pull-up Pushover	1.5 g 0.75 g
Simulated Engine Failures	5000	ON	BARO	OFF	OFF	100	Level	
		ON	OFF	OFF	OFF	100	Climb	

NOTES

[1] 100% rotor speed, engine start gross weight 15,07[illegible] pounds, engine start longitudinal center of gravity at fuselage station 359.7.
[2] At field elevation.
[3] BARO: Altitude hold mode on with barometric reference.
[4] BUCS: Backup control system.
[5] DOCS: Digital-optical control system.
[6] IRP: Intermediate rated power.
[7] AGL: Above ground level.
[8] RAD: Altitude hold mode on with radar altitude reference.
[9] AFCS: Automatic Flight Control System.

RESULTS AND DISCUSSION

GENERAL

6. A Preliminary Airworthiness Evaluation of the UH-60A with the Advanced Digital Optical Control System was conducted by AEFA. The test was conducted at the Boeing Vertol Flight Test Center at Wilmington, Delaware, with the support of the Boeing Vertol Company. Tests were conducted at the conditions shown in table 1. Three enhancing characteristics were found: (1) the ease in rolling to and maintaining a desired bank angle, (2) the capability to maintain "hands off" stabilized hover with all selectable modes engaged, and; (3) the capability of the barometric altitude hold mode to maintain altitude during simulated instrument flight tasks. Additionally, no deficiencies and 19 shortcomings were found. The shortcoming classification of problem area is based on the proposed use of the ADOCS as a technology demonstrator. Some of the problem areas would be more serious in a production aircraft. The safety, performance, and reliability of the ADOCS were found to be adequate to proceed to a user demonstration. Additionally, the BV user demonstration flight plan was found to be satisfactory.

HANDLING QUALITIES

Control Transfers

7. The objective of the test was to evaluate any delays in transferring control or any aircraft transient response resulting from the transfer. Transfer of control from the BUCS to the ADOCS controls and reversion to the BUCS controls were accomplished.

8. No delays were observed when engaging the ADOCS or reverting from ADOCS to BUCS. Minimal aircraft response occurred when engaging the ADOCS and resulted in a change of approximately +0.2g with less than 1 degree of attitude change in the pitch, roll and yaw axes. No significant aircraft response occurred when reverting from the ADOCS to BUCS. Control transfer characteristics of the ADOCS are satisfactory.

Level Flight

9. The objective of these tests was to evaluate the capability of the ADOCS to maintain trimmed flight. The effectiveness of the heading hold mode and altitude hold mode (referenced to both radar altitude and barometric altitude) were evaluated.

10. During accelerations and decelerations between 40 and 150 knots indicated airspeed (KIAS) while maintaining level flight

without pilot commanded yaw or roll input, the aircraft would occasionally enter slightly uncoordinated flight. While accelerating, the pilot's turn and slip instrument showed a maximum of 1/2 to 3/4 ball widths right of center (right sideslip). After stabilizing at the target airspeed, the aircraft would sometimes return to trimmed flight; however, a pilot yaw control input was usually required. The aircraft occasionally entered an uncommanded right turn, with a bank angle between 5 and 7 degrees and 1/2 ball width right of center while decelerating between level flight airspeed points. Pilot input was sometimes required to return to level flight (0 degree bank angle) although the out of trim condition was occasionally self-correcting without pilot input. Uncoordinated flight resulting from changes in airspeed is a shortcoming.

11. The barometric altitude hold mode maintained the aircraft pressure altitude within $\pm$10 feet at level flight trim airspeeds between 40 and 150 KIAS and within $\pm$50 feet during accelerations and decelerations using 5 degree nose down and 10 degree nose up attitudes. Accelerating between 130 and 150 KIAS using a 5 degree nose down attitude resulted in an approximate 40 percent torque increase as the barometric altitude hold attempted to maintain aircraft altitude during the acceleration. At the gross weight and density altitude test conditions, this produced a one to two second transient overtorque of 105 percent. The tendency to overtorque with barometric altitude hold engaged while accelerating at high airspeeds is a shortcoming.

12. The barometric altitude hold mode was engaged at 80 KIAS and the aircraft was accelerated to 150 KIAS. Barometric altitude hold was deselected after stabilizing at 150 KIAS for approximately 15 seconds. The change in modes resulted in a smooth uncommanded down collective input equivalent to 50 percent torque reduction in approximately 7 seconds. During a subsequent level flight acceleration, barometric altitude hold was engaged at 80 KIAS. The aircraft was then accelerated using a 5 degree nose down attitude and barometric altitude hold was deselected at 130 KIAS during the deceleration. This resulted in a more rapid uncommanded downward collective movement (equivalent to 1-1/2 inches per second). This uncommanded collective input after disengaging altitude hold at a speed different from the engagement speed is a shortcoming.

Turning Flight

13. The objectives of this test were to evaluate the aircraft handling qualities during maneuvering flight, to evaluate the capability of the altitude hold mode to maintain altitude in

turns, and to evaluate the automatic switching between heading hold and turn coordination modes. Constant collective turns at incremental bank angles up to 60 degrees were used, with altitude hold mode on and off. Heading hold mode and turn coordination were further evaluated by rapidly rolling into and out of turns, and by conducting rapid roll reversals. Accelerating turns from 30 to 70 KIAS and decelerating turns from 70 to 30 KIAS were accomplished to evaluate the engagement/disengagement of turn coordination (which occurs at 50 knots with roll attitude, roll rate, and yaw rate within constraints), and the change in lateral control laws from attitude command at low speed to rate command at high speed.

14. No uncommanded aircraft responses were observed during automatic ADOCS switching from the heading hold mode to turn coordination or with lateral control law change from attitude to rate command while performing turning flight. Bank angle control required minimal pilot input during forward flight maneuvers. It was extremely easy to roll to a desired bank angle with accurate lateral control response and no overshoot (HQRS 2). The ADOCS maintained the desired bank angle with no requirement for lateral control input. The capability to easily roll to and maintain a desired bank angle is an enhancing characteristic.

15. Turns were performed using only lateral control inputs. Occasionally the aircraft would enter uncoordinated flight as much as 1/2 to 3/4 ball widths out of trim. This condition was rarely self-correcting and normally required a pilot commanded yaw input to return the aircraft to ball-centered flight. This uncoordinated flight resulting from changes in bank angle is a shortcoming.

16. Turns were performed with the barometric altitude hold mode engaged. Altitude hold maintained aircraft altitude within ± 50 feet with bank angles of 45 degrees or less. Altitude variation was slightly greater using bank angles greater than 45 degrees although after rolling out of the turn, the aircraft regained its original altitude within approximately 15 seconds. The altitude hold mode tended to cause an overtorque at 120 KIAS or greater with bank angles in excess of 45 degrees at the gross weight and density altitude test conditions. The tendency to overtorque with barometric altitude hold engaged at high airspeeds and bank angles is a shortcoming.

17. A normal grip on the right sidearm controller often produced an unintentional yaw input when attempting to make a lateral only control input. This biomechanical coupling was possibly caused by the control grip design and lack of multiple axis adjustments.

The unintentional directional inputs during pilot-commanded roll inputs is a shortcoming.

Dynamic Stability and Controllability

18. The objectives of this test were to evaluate the dynamic stability and control response of the ADOCS-equipped aircraft. Step and pulse inputs in the longitudinal, lateral, directional and collective controls were input electrically through the AFCS control processors, and the subsequent aircraft response was recorded. Additionally, control steps were input manually in all four axes.

19. The response to inputs in all control axes in forward flight were highly damped with the aircraft returning to the trim condition after the input was removed. The directional step input resulted in one overshoot when the input was removed but was not objectionable. The inputs were induced at a hover with various combinations of selectable modes engaged. Aircraft response with all selectable modes engaged was highly damped with no overshoots. With all modes except velocity stability engaged, the aircraft responses in pitch and roll were slightly less damped with one to two overshoots. Aircraft response to pitch and roll inputs were neutral to lightly damped with only heading hold mode engaged. Pilot action was required to recover from these inputs. The dynamic stability and control response of the ADOCS-equipped aircraft were satisfactory.

Ground Handling Characteristics

20. Ground handling characteristics were evaluated during normal taxi operations. Ground taxi was performed with heading hold mode engaged. The ADOCS flight control system is designed to position the collective acuator to approximately 15% from the full down position when the pilot removes force from the collective control, all three landing gear are on the ground, and the collective position is at approximately 30% or less from full down. This collective position provided sufficient thrust for ground taxi on a level surface at minimum test gross weight (approximately 13,200 pounds) without the aircraft becoming too light on the landing gear. Pilot input to increase collective was required when taxing at heavier gross weights, up hill or into the wind. With no pilot input on the right sidearm controller, the main rotor tip-path plane appeared to be approximately level and tail rotor thrust sufficient to oppose the main rotor torque with the collective equivalent to 15% from full down. Ground taxi was accomplished by holding a forward pressure on the right sidearm controller to tilt the main rotor tip-path-plane

slightly forward from the level position. Visual reference to the tip-path-plane was required to determine how much forward cyclic input was being commanded since there is essentially no sidearm controller position cue, and force cues are virtually impossible to equate to tip-path-plane position. The poor cues to rotor tip-path-plane position during ground operations is a shortcoming.

21. Ground taxi normally required a constant moment on the right sidearm controller to maintain the desired heading particularly when taxiing with a cross wind or under conditions which required a collective position other than 15% from full down. The magnitude of the moment required was such that heading control during ground taxi became fatiguing even for short periods of time. The high moment required on the directional controller during ground taxi is a shortcoming.

22. Photographs of the right sidearm controller are presented in photos 1 and 2. The intercom and radio transmit switches are located on the upper, forward side of the controller grip. It was difficult to actuate these switches while maintaining the required rotational force on the control grip for heading control during ground taxi. The difficulty in using switches on the right sidearm controller while making directional inputs is a shortcoming.

Climbs and Descents

23. The objective of this test was to evaluate the capability of the aircraft to maintain coordinated flight during climbs and descents, and to evaluate the altitude hold mode. The capability to adjust the rate of climb or descent was also evaluated.

24. Forward flight climbs and descents were performed with heading hold only and barometric or radar altitude hold engaged. During changes in the rate of climb or descent, the aircraft occasionally would enter uncoordinated flight as much as 1/2 to 3/4 ball widths out of trim. This condition was rarely self-correcting and normally required a pilot commanded yaw input to return the aircraft to ball centered flight. This uncoordinated flight resulting from changes in power is a shortcoming.

25. The ADOCS collective control is designed to operate as a proportional controller if an altitude hold mode is selected. That is, the change in engine torque (and the aircraft rate of climb) is proportional to the force applied to the collective control (see table 2, app B). To maintain a constant rate of climb or descent (i.e., a constant torque in the climb or descent)

the pilot must maintain a constant force on the collective control. The difficulty in maintaining a constant force on the controller makes it difficult to maintain a desired engine torque. The difficulty in maintaining a desired engine torque during a climb or descent with altitude hold on is a shortcoming.

26. The ADOCS collective flight control is designed to operate as a proportional plus integral controller when an altitude hold mode is not selected. With this type control law, a constant force on the collective will continue to drive the collective actuator to its limit stop because the integrator acts as a trim follow-up as long as there is a pilot commanded force on the collective. Once the integrator senses zero collective force, trim follow-up stops. Because the trim follow-up lags the commanded collective position, the new trim position may be less than the maximum commanded position. For example, to initiate a climb using 90% torque from level flight at 50% torque, the pilot would apply an upward force on the collective control sufficient to attain 90% torque. If he maintains a constant force, the integrator will continue to increase collective position (and torque). If he immediately releases the force to zero after reaching 90%, the torque will decrease to a value between 50% and 90% because of the trim follow-up lag. In order to maintain 90% torque, the pilot must decrease force at the same rate the integrator is increasing the collective trim. This design makes it difficult to set a desired engine torque with altitude hold off. The difficulty in setting desired engine torque with altitude hold off is a shortcoming.

27. The collective control operates as a proportional or proportional plus integral controller depending on whether altitude hold is engaged or not. Thus, the pilot must use different control techniques when making power changes depending on the control laws (proportional or proportional plus integral) of the collective control. The requirement to remain aware of collective control laws to obtain a desired power setting is a shortcoming.

28. Forward flight and vertical climbs were performed with heading hold, and radar altitude hold engaged. The ADOCS collective control system is designed such that at 1000 feet above ground level in a climb radar altitude hold automatically disengages and the collective control laws change from porportional to proportional plus integral. The effect of this control law change is that the collective blade angle and engine torque begin to increase rapidly although the pilot maintains a constant force on the collective control (fig. 1, app E). To prevent an overtorque condition due to the collective control law change, close attention to radar altitude and engine torque is required.

The collective control input caused by control law change when radar altitude hold mode disengages automatically at 1000 feet is a shortcoming.

29. Forward flight climbs and descents were made with heading hold engaged. The barometric altitude hold mode was engaged at a target altitude while in a climb or descent at 700 feet per minute. The aircraft captured the target altitude with approximately a 20 foot overshoot without a pilot input on the collective control. However, after engaging altitude hold in a descent and stabilizing at the new altitude, the altitude hold was deselected, and the collective actuator drove downward which caused the aircraft to enter an uncommanded descent of approximately 1200 feet per minute (fig. 2, app E). Similarly, after engaging at the engaged altitude, deselecting altitude hold resulted in an uncommanded climb of approximately 1200 feet per minute. The uncommanded collective control input after disengaging altitude hold if altitude hold mode was engaged in a climb or descent is a shortcoming.

Takeoff and Landing Characteristics

30. The objectives of this test were to evaluate the ease with which takeoffs and landings could be accomplished and to check for aircraft transient response during the control law changes that occur upon landing or takeoff. Normal and rapid vertical takeoffs were made from a level surface. Rolling takeoffs and landings at 30 knots and landings from a hover were accomplished. Landings on an incline were accomplished in all four directions.

31. Normal and rapid vertical takeoffs and landings were performed with various combinations of selectable modes. Takeoff with AFCS only engaged (i.e., no selectable modes) required minimal pilot control inputs with small directional inputs being required to maintain heading within ±2 degrees (HQRS 3). Heading control was better with heading hold engaged (±1 degree heading variation) with no yaw axis pilot input and very small pitch and roll axis pilot inputs (HQRS 2). Various problems were encountered (uncommanded aft cyclic control inputs and AFCS disengagements) with other modes engaged during takeoffs and landings. Figure 3, appendix E shows an abrupt, uncommanded aft longitudinal input during a vertical landing with all modes engaged. These problems were not repeatable and their cause was not determined. The uncommanded aft cyclic control inputs after landing with all selectable modes engaged is a shortcoming. Takeoffs and landings with velocity stability, hover assist and altitude hold engaged should not be performed during the user demonstration flights.

32. Left and right 8 degree side slope and 5 degree nose up and nose down landings and takeoffs were evaluated with heading hold engaged. The pilot technique required to perform slope takeoffs and landing using a limited displacement sidearm force controller is significantly different from those used with conventional helicopter controls where control stick position provides pilot cues for rotor tip-path-plane position. The slope landing and takeoff maneuvers require slow and smooth control inputs to prevent overcontrolling. The landings and takeoffs required a series collective and cyclic pilot inputs attempting to minimize pitch and roll accelerations and rates while one or more of the landing gear is contacting the ground. The stability provided by the ADOCS AFCS partially offset the increased pilot workload caused by the lack of stick position cues although the task remained more difficult to perform with the sidearm force controls than the conventional flight controls. The side slope takeoff technique initially requires some up collective until a roll attitude change is perceived, followed by some lateral cyclic toward the slope to keep the aircraft attitude equal to or slightly less than the degree of the slope. This is followed by slightly more up collective, then lateral cyclic repeating the iterations and reducing the up slope lateral cyclic pressure as the aircraft roll attitude approaches wings level and the aircraft leaves the ground. Side slope landings are performed in a reverse but similar manner. Considerable pilot compensation was required to perform side slope landing using the ADOCS (HQRS 5). Poor cues to rotor tip-path-plane position during slope landings/takeoffs is a shortcoming.

33. Nose down and up landings and takeoffs require pilot techniques similar to those described above. The 5-degree nose-down landings required considerable compensation (HQRS 5) and 5-degree nose-down takeoffs were accomplished with moderate pilot compensation (HQRS 4). Occasional AFCS failures in one or more channels occurred while performing slope operations sometimes causing reversion to the ADOCS PFCS. These failures were unexplained and not repeatable. Frequent ADOCS monitor trips (reversion of control to BUCS) also occurred in the pitch and roll axes when performing slope landings and takeoffs. The AFCS failures experienced during slope landings are a shortcoming.

34. Rolling takeoffs and landings required slow and smooth controller inputs and were performed with heading hold and velocity stability modes engaged. Aircraft roll attitude was the pilot cue to determine lateral cyclic pressure required during the rolling takeoff. The ADOCS monitor caused aircraft control to revert to BUCS (monitor trips) on several rolling takeoffs as the aircraft became airborne. Considerable pilot

compensation was required to prevent overcontrolling and execute the maneuver smoothly (HQRS 5). Rolling landings required slightly less pilot compensation (HQRS 4). It was imperative to release longitudinal control forces after landing gear touchdown and use lateral and directional inputs only to control bank angle and heading. Aerodynamic braking (aft longitudinal control) could not be used since there were no pilot stick position cues to correlate tip-path-plane position. Pilot longitudinal cyclic inputs often caused undesirable fore or aft tip-path-plane movement which resulted in ADOCS monitor trips. Poor cues to rotor tip-path-plane position during rolling takeoffs and landings is a shortcoming.

35. The ADOCS is designed such that if the sidearm controller is displaced from its detent greater than 25 percent of full travel with either main landing gear on the ground a high gain lag path is added to the control laws which effectively provides more actuator output per amount of controller input. If the pilot's controller is displaced just outside the 25% threshold value, the rapid increase in actuator travel (see fig. 4, app E) causes a rapid aircraft attitude change. Additionally, with the tail wheel on the ground all ADOCS AFCS inputs are disengaged except roll and all controls become proportional except collective. These design features produce undesirable control transients which occur frequently when performing slope operations and rolling takeoffs and landings. The control transients due to control law changes during slope and rolling landings/takeoffs is a shortcoming.

Low Speed Flight Characteristics

36. The objectives of this test were to evaluate the handling qualities of the ADOCS in low speed flight with and without the selectable modes engaged, and to check for any control system transients caused by automatic disengagement of these modes. Tests were conducted at the conditions listed in table one.

37. Unintentional pilot induced directional inputs occurred during low speed flight maneuvers while attempting to make constant rate heading changes. These unintentional inputs were manifested as slight yaw accelerations or jerky heading changes and were most pronounced while in moderate vibration low speed flight environments such as translational lift. The unintentional yaw control inputs during yaw rate turns in a flight region of moderate airframe vibrations was related to the high directional control sensitivity and high moment. The high directional control sensitivity and high moment is a shortcoming.

38. Right sideward, rearward, and left sideward flight with relative wind azimuths at 90°, 180°, and 270°, respectively from a hover to 40 knots and forward flight from a hover to 60 knots were performed. This low speed flight was conducted with heading hold plus various combinations of selectable modes engaged. No switching transients were observed while operating with heading hold plus velocity stability and/or radar altitude hold engaged. The hover assist mode can be engaged at speeds ranging from a hover to 8 knots ground speed. This mode automatically disengages at doppler ground speeds greater than 25 knots. Automatic disengagement of hover assist produced rapid uncommanded lateral inputs which were perceived as $\pm 1°$ roll oscillations (fig. 5, app E). Three seconds after hover assist automatic disengagement, a control law change produced another uncommanded roll or pitch control input (fig. 6). This uncommanded input produced a 5° to 7° increase in roll attitude during sideward flight and 5° to 8° nose-up or nose-down pitch attitude change in rearward and forward flight, respectively. The rapid, uncommanded lateral inputs when hover assist mode disengages automatically at 25 knots is a shortcoming. The control transients caused by control law changes 3 seconds after hover assist mode automatic disengagement is also a shortcoming.

39. The radar altitude hold mode maintained altitude within ± 1 foot while at a hover over a homogeneous surface. This mode was engaged while hovering over the runway surface and the aircraft was then hovered over a grass area. The change in surface texture resulted in the aircraft climbing 15 feet. The radar altitude hold mode maintained absolute altitude ± 2 feet during the low speed accelerations over the runway. However, during the deceleration from 40 knots sideward/rearward or 60 knots forward, without a pilot induced collective command, the aircraft climbed between 11 and 30 feet above the engaged altitude. The aircraft then descended to the original altitude after returning to a hover. On one occasion, following an uncommanded climb, the aircraft descended 7 feet below the original altitude then climbed back to the original engaged altitude (one altitude overshoot). The uncommanded altitude gains during low speed decelerations with radar altitude engaged is a shortcoming.

Instrument Flight Capability

40. The objective of this test was to evaluate handling qualities during flight in simulated instrument flight conditions (IMC). The IMC tasks evaluated included: climb, enroute navigation, holding, and approach. Heading hold and altitude hold modes were evaluated during these tests.

41. The simulated IMC tasks were performed at 100 KIAS in light to moderate turbulence air conditions. Climbs and descents at 400 to 600 feet per minute were performed with heading hold engaged. Barometric altitude hold was engaged at the target level-off altitude. The aircraft leveled-off at the altitude at which barometric altitude hold was engaged with only a 10 to 20 foot overshoot before returning to the target altitude. Additionally, altitude changes were performed with the altitude hold mode engaged. The aircraft leveled-off at the altitude at which the force was released from the collective with a small overshoot similar to that described above. The altitude capture capability of the ADOCS was satisfactory. Uncommanded collective control input resulting in a climb or descent after disengaging altitude hold if altitude hold mode was engaged in a climb or descent was noted and is a shortcoming (described in paragraph 29).

42. A simulated instrument holding pattern was established at 100 KIAS using standard rate turns (3° per second) with heading hold and barometric altitude hold mode engaged. Very little pilot compensation was required to roll to a desired bank angle (HQRS 2). After attaining the desired bank angle, the ADOCS maintained the bank without additional pilot input (HQRS 1). Bank angles were evaluated up to 60° with similar angle of bank retention characteristics. The capability to easily roll to and maintain a desired bank angle is an enhancing characteristic as previously stated in paragraph 14.

43. Barometric altitude hold mode maintained altitude within ± 10 feet while performing standard rate turns, simulated procedure turns and constant altitude simulated course tracking tasks. This altitude tolerance was maintained without any pilot collective input (HQRS 1). The capability to maintain altitude while performing simulated IMC tasks is an enhancing characteristic.

44. Heading control required minimum pilot compensation while performing simulated course tracking tasks (HQRS 3). Pilot directional control inputs were occasionally required due to the aircraft entering uncoordinated flight as described in paragraphs 10, 15, and 24.

Mission Maneuvering Characteristics

45. The objectives of this test were to evaluate the capability to conduct various mission tasks using ADOCS and also to evaluate the BV flight plan for the user demonstration. Appendix D contains a copy of the BV user demonstration flight plan. Use of the various selectable modes were evaluated.

46. Nap-of-the-earth (NOE) and low speed maneuvering flight were performed with heading hold and various combinations of the other selectable modes engaged with surface winds of 12 knots with gusts to 18 knots. Stable in-ground effect and out-of-ground effect hover was easily performed with all selectable modes engaged. The hover assist mode uses doppler inputs to maintain hover position when the aircraft is within the constraints listed in table 3, appendix B. The ability of the ADOCS to maintain a stationary hover was limited by an inherent doppler characteristic known as doppler drift. Hands-off hover was performed for two minutes and resulted in the aircraft drifting laterally ±1 foot, forward approximately 10 feet, heading change less than one degree while maintaining altitude ±1 foot. The capability to perform hands-off hover for short periods of time with all modes engaged is an enhancing characteristic.

47. Additional NOE maneuvers included vertical and lateral unmasking and remasking, moderately aggressive and aggressive low speed maneuvering flight, rapid accelerations and quickstops. No mode or control law switching transients were apparent except the automatic disengagement of hover assist at 25 knots (see paragraph 37). Low speed maneuvering flight was easily performed with heading hold engaged although aircraft stability was slightly increased with the addition of velocity stability. Aggressive low speed maneuvering flight with heading hold or heading hold and velocity stability engaged was also easy to perform. The aircraft retained sufficient agility even with the increased stability provided by the velocity stability mode. Occasional ADOCS monitor trips were encountered during aggressive low speed maneuvering, particularly when maneuvering at tree top level where wind turbulence was the greatest. ADOCS monitor trips consistently occurred during quickstops with nose-up attitudes greater than 18 degrees. It was inappropriate to use the altitude hold mode when performing NOE maneuvering flight due to tail wheel proximity to the ground when flying low over undulating terrain or performing low altitude quickstop maneuvers. However, when the selected terrain flight altitude provided sufficient aircraft to ground clearance, the radar altitude hold mode was effectively used. When performing low level maneuvers (such as NOE flight) which provide the pilot good, visual cues to aircraft altitude, the switching of collective laws (between proportional or proportional plus integral), was not a problem as it had been during higher altitude flight.

48. Air-to-air and air-to-ground tracking tasks were performed accelerating and decelerating between 50 and 130 KIAS utilizing bank angles up to 60 degrees, pitch attitude changes from 20 degrees nose-up to 15 degrees nose-down and power changes between

20% and 70% torque. These maneuvers were performed with heading hold engaged. Out-of-trim conditions encountered during maneuvering flight, or during changes in airspeed or power remained a problem. The aircraft was easily returned to trim but required the pilot's attention to be diverted to the cockpit gages. Frequent cross checks to the engine torque gage were also required due to the lack of collective position cues.

49. The maneuvers proposed on the BV user demonstration flight plan were demonstrated by the BUCS pilot then duplicated by the ADOCS pilot. The flight plan maneuver sequence was designed to demonstrate the ADOCS capabilities in a logical build-up. Adequate flight safety is provided since the BUCS pilot actively follows all ADOCS flight control movements and can readily disengage the ADOCS by activating either of two switches, one on the BUCS cyclic or one on the collective. The user demonstration flight plan is satisfactory. AATD should proceed to the ADOCS user demonstration.

Automatic Flight Control System Simulated Failures

50. The objective of this test was to evaluate handling qualities during and following failures of the AFCS. The AFCS failures were simulated by disengaging the system with the aircraft in a various flight conditions. Handling qualities were evaluated with the AFCS off, in level flight, climbs, descent, turns, pull-ups, pushovers, and landings.

51. An AFCS disengagement causes ADOCS reversion to PFCS. Aircraft control was never in question with any of the AFCS failures. The ADOCS PFCS flying qualities were similar to the UH-60A with both stability augmentation systems disengaged. The degraded mode aircraft flying qualities following ADOCS AFCS failure are adequate for a user demonstration.

Simulated Engine Failures

52. The objective of this test was to ensure that the safety pilot could safely take control of the aircraft following an engine failure. Test conditions are listed in table 1.

53. Simulated single-engine failures were performed by retarding an engine power control lever to the idle position. Engine failure during level flight required no pilot control inputs and manual reversion to BUCS was not necessary since the operating engine picked up the load of the failed engine without exceeding torque or temperature limits. No aircraft reaction was observed except an approximate one degree heading change. Engine failure

in a climb at 1000 feet per minute using 60% torque was also evaluated. No pilot inputs were made. A slight ($\pm 2°$) highly damped yaw oscillation was observed. Manual reversion to BUCS was performed after a 5-second delay at which time the operating engine had reached its temperature limit and the rotor speed drooped to 95%. The response of the ADOCS to a simulated engine failure is satisfactory.

CONCLUSIONS

GENERAL

54. Within the tested flight envelope, the ADOCS is safe to proceed to user demonstration.

55. The performance and reliability of the ADOCS system during this evaluation were adequate for a productive user demonstration, although moderately aggressive maneuvers or less aggressive maneuvers in gusty conditions will cause automatic reversion to BUCS via the DOCS monitor.

56. The user demonstration flight plan is satisfactory.

57. Three enhancing characteristics, no deficiencies and 19 shortcomings were found during this evaluation.

ENHANCING CHARACTERISTICS

58. The following three enhancing characteristics of the ADOCS were found:

a. The capability to easily roll to and maintain a desired bank angle (para 14 and 42).

b. The capability to maintain "hands off" hover with all modes engaged (para 46).

c. The capability of the barometric altitude hold mode to maintain altitude during simulated IMC tasks (para 43).

SHORTCOMINGS

59. The following shortcomings were found:

a. Transients due to control law changes during slope and rolling landings/takeoffs (para 35).

b. Control transients caused by control law changes 3 seconds after hover assist mode automatic disengagement (para 38).

c. Collective control input caused by control law change when radar altitude hold mode disengages automatically at 1000 feet (para 28).

d. Requirement to remain aware of collective control laws to obtain a desired power setting (para 27).

e. Rapid, uncommanded lateral inputs when hover assist mode disengages automatically at 25 knots (para 38).

f. Collective control input after disengaging altitude hold if altitude hold mode was engaged in a climb or descent (para 29 and 41).

g. Collective control input after disengaging altitude hold at a speed different from the engagement speed (para 12).

h. Uncommanded aft cyclic input after landing with all selectable modes engaged (para 31).

i. Poor cues to rotor tip path plane position during ground operation and slope and rolling landings/takeoffs (paras 20, 32, and 34).

j. High moment required on the directional controller during ground taxi (para 21).

k. High directional control sensitivity and high moment required (para 37).

l. Difficulty in using switches on right-hand controller while making directional inputs (para 22).

m. Unintentional directional inputs during pilot-command roll inputs (caused by grip design and lack of multiple axis adjustments) (para 17).

n. Tendency to overtorque with barometic altitude hold engaged at high airspeeds and bank angles (paras 11 and 16).

o. Difficulty in setting desired engine torque with altitude hold OFF (para 26).

p. Difficulty in maintaining engine torque in a climb or descent with altitude hold ON (para 25).

q. Uncoordinated flight resulting from changes in airspeed, bank angle or power (para 10, 15, and 24).

r. Uncommanded altitude gains during low speed decelerations with radar altitude engaged (para 39).

s. AFCS failures experienced during slope landings (para 33).

RECOMMENDATIONS

60. Takeoffs and landings with velocity stability, hover assist and altitude hold engaged should not be performed during the user demonstration flights (para 31).

61. AATD should proceed to the ADOCS user demonstration flight phase (para 49).

APPENDIX A. REFERENCES

1. Letter, AVSCOM, AMSAV-8, 11 December, 1986, subject: Preliminary Airworthiness Evaluation of an Advanced Digital/Optical Control System in a UH-60A Helicopter. (Test request)

2. Technical Manual, TM55-1520-237-10, *Operator's Manual for Army UH-60A Helicopter*, 21 May 1979 with change 39, dated 7 October, 1986.

3. Letter, AMSAV-E, 11 March, 1987, subject: Airworthiness Release for JUH-60A, S/N 78-23012, Equipped with the Advanced Digital Optical Control System (ADOCS), with revision 1 dated 9 April, 1987.

APPENDIX B. DESCRIPTION

GENERAL

1. The advanced digital optical control system (ADOCS) consists of a primary flight control system (PFCS), replacing the standard mechanical controls which is used by the pilot to control the aircraft, and an automatic flight control system (AFCS) which is used to augment the basic UH-60A stability and modify the aircraft response to pilot commands. The ADOCS incorporates limited-displacement controllers for pilot inputs (right-side pilot station only (photo 1)). These controllers measure and transmit pilot command inputs optically to digital flight control processors. The flight control processors shape the control inputs and send optical signals to control the main and tail rotor actuators. For this evaluation, a three-axis, side-arm controller was used for longitudinal, lateral and directional inputs (photo 2), and a separate side-arm control was used for collective (photo 3). Both optical and electronic sensors are used to measure aircraft state variables and actuator positions. The output of these sensors is transmitted either electrically or optically to the PFCS and AFCS processors. A unique feature of the ADOCS is that the PFCS and AFCS processors are separate and therefore the aircraft augmented stability and controllability can be changed independently. The left-side pilot station incorporates the standard UH-60A pilot controls, which are back driven to follow the total control commands sent to the rotors, and which are used as a safety backup control system (BUCS). The PFCS software version flown during this test was numbered 400-ACN-021 dated 21 March 1987. The AFCS software was numbered 800-ACN-025 dated 2 April 1987.

Primary Flight Control System

2. The PFCS software provides proportional control with command shaping. The pilot commands are received and shaped by the PFCS. This command shaping consists of a deadband about zero controller position (and force) with low sensitivity (actuator movement per controller movement) about this deadband, a zone of increasing sensitivity at larger displacements, and constant sensitivity at the largest displacements (fig. 1 shows a typical shaping function). After shaping, the commands are mixed in the PFCS and sent to the flight control actuators. The unmixed commands are also sent to the AFCS processor (see fig. 2). The PFCS makes directional inputs to correct for yaw moments due to collective application. The amount of this collective-to-yaw compensation is optimized at 80 knots. With power on the PFCS, but the aircraft being flown using the BUCS, the PFCS will track the actuator positions so that the PFCS can be engaged with no control transients being introduced. With the aircraft on the ground,

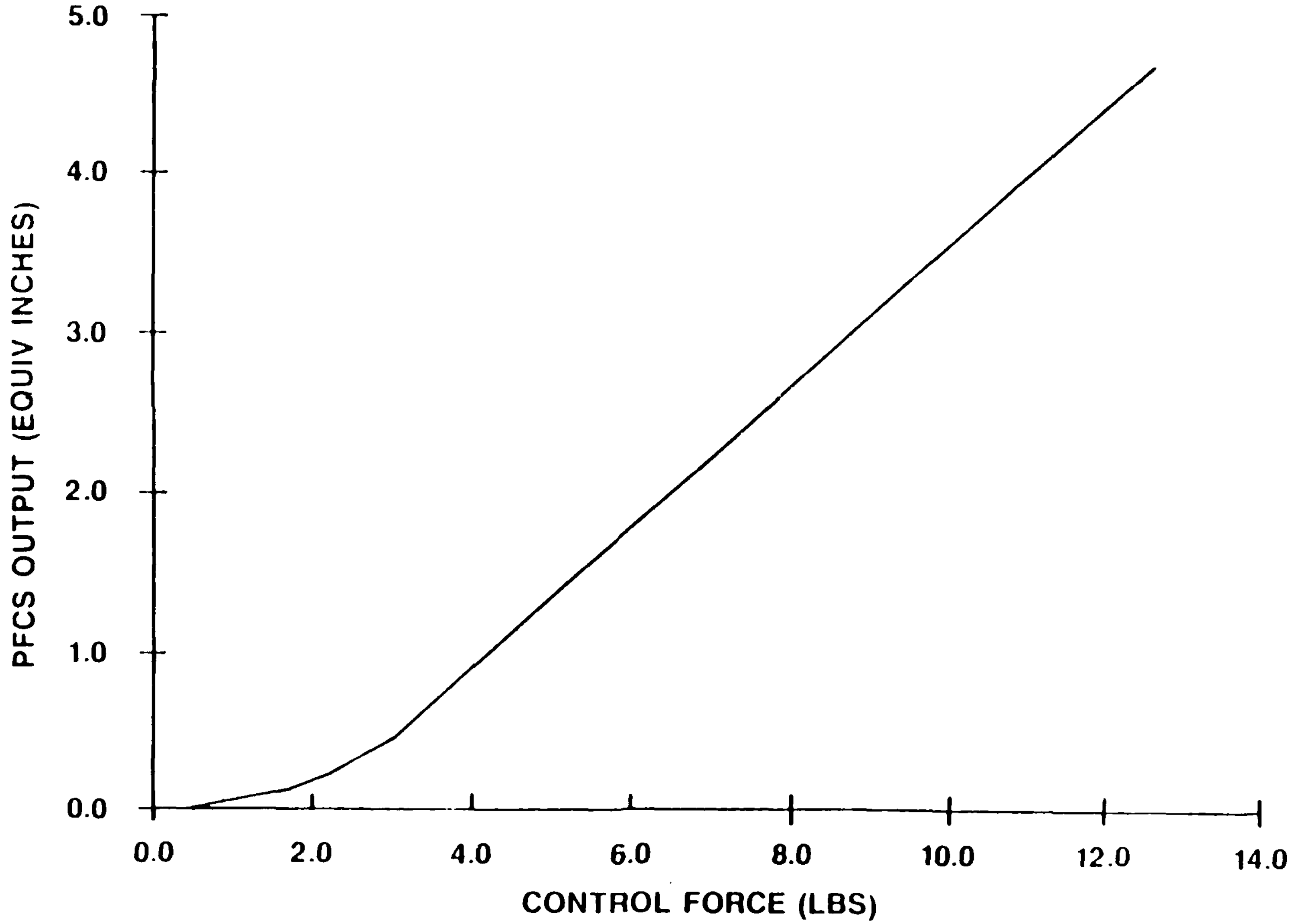


Figure 1. Longitudinal Command Shaping Function

a beep trim is provided by momentary switches on the controls. Also, with the aircraft on the ground, the PFCS provides proportional control only, within 25% of the trim position. At larger control displacements, the PFCS output for a given controller input is significantly increased.

Automatic Flight Control System

3. The AFCS modifies the aircraft response to pilot commands and augments the basic UH-60A stability when the AFCS is selected on and the aircraft is off the ground. The AFCS consists of a core AFCS and four selectable modes: heading hold, altitude hold, velocity stability, and hover assist. Altitude hold mode may be selected with either radar or barometric altitude as a reference. The hover assist mode has ground speed hold and ground position hold features. Figure 2 presents a schematic of the PFCS and AFCS. The unmixed pilot commands are sent from the PFCS to the AFCS where a desired response is calculated (see "command model" in fig. 2). This desired response is compared to the actual, measured aircraft response. Any error between the desired and actual response causes a command to be sent to the PFCS which is summed with the pilot command and sent to the actuators to eliminate the error. Gust upsets will generate such an error and will cause a command to correct the upset. Control inputs may cause large aircraft response without generating a large error. Therefore, even with high damping augmentation, the aircraft response to pilot inputs will not be reduced as it would be in a conventional stability augmentation system. The AFCS is also used to minimize control coupling of the basic aircraft (such as pitch with yaw rate and yaw with collective) as well as to change between basic control laws (such as changing from rate to attitude command).

4. The control laws used in the basic core AFCS are shown in table 1. Table 2 shows control laws which are changed as a result of selectable mode engagement. Table 3 presents for each selectable mode, the constraints which must be met to engage the mode and the conditions under which the mode will be automatically disengaged.

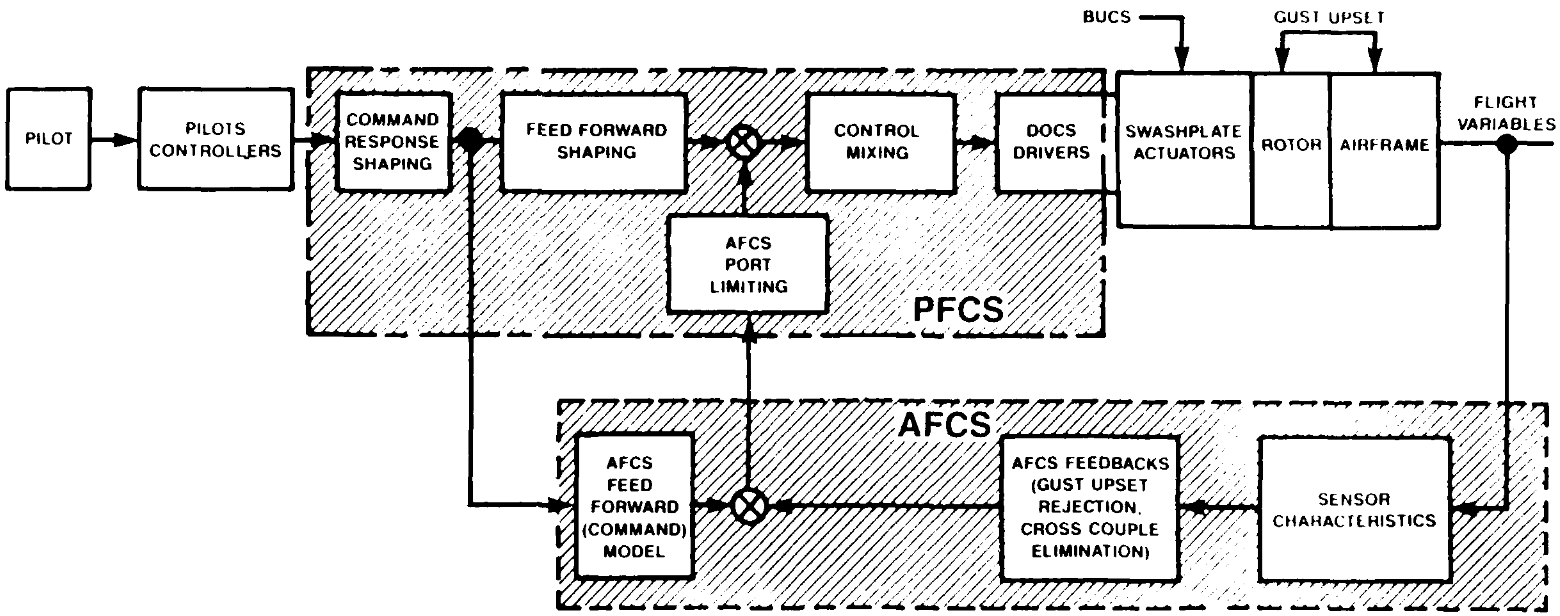


Figure 2. ADOCS Flight Control System Schematic

Table 1. Core AFCS Control Laws[1]

Axis	Hover/Low Speed		Switching Speed	Forward Flight		Remarks
	Command	Stability		Command	Stability	
Longitudinal	Pitch Attitude	Pitch attitude and derived pitch rate	47 knots accelerating 42 knots decelerating	Pitch Attitude	Airspeed[2]	
Lateral	Roll Attitude	Roll Attitude and Rate	47 knots accelerating with roll rate less than 1 deg/sec. 42 knots decelerating with roll rate less than 1 deg/sec and roll attitude less than 3 deg	Roll rate and yaw rate (turn coordination)	Roll Attitude	Turn coordination if airspeed >50 knots and lateral control outside software dead band.
Directional	Yaw Acceleration	Yaw Rate	Control sensitivity gradually decreases from 60 to 80 knots	Yaw Acceleration	Yaw Rate	Trim schedule of control versus airspeed
Vertical	Vertical Acceleration (collective rate)	None	Not applicable	Vertical Acceleration	None	No automatic change in control laws.

NOTES:

[1]All selectable modes OFF.
[2]Airspeed and pitch attitude complementary filter.

Table 2. ADOCS Control Law Changes with Selectable Modes Engaged

Axis	Heading Hold		Velocity Stability		Hover Assist		Altitude Hold (Radar or Baro)	
	Command	Stability	Command	Stability	Command	Stability	Command	Stability
Longitudinal	--	--	Pitch Attitude	Longitudinal groundspeed (below 42 knots) Longitudinal airspeed (above 47 knots)	Longitudinal groundspeed	Longitudinal groundspeed or position hold		-- --
Lateral	--	--	Roll Attitude	Lateral groundspeed	Lateral groundspeed	Lateral groundspeed or position hold		--
Directional	Yaw rate	Heading	--	--	Yaw rate	Heading	-	--
Vertical	--	--	--	--	Vertical Velocity	Altitude Hold	Vertical Velocity	Altitude Hold[1,2]

NOTES:

[1]Also schedules of collective control versus airspeed and bank angle (only above 40 knots for altitude hold).
[2]Gain constant 0-40 knots, schedule with airspeed reduces over 40-80 knots range, gain constant above 80 knots. Effective gain higher with radar reference than with barometric reference.

Table 3. ADOCS Selectable Mode Engagement/Disengagement Conditions

Mode		Engagement Constraints	Automatic Disengagement Constraints	Remarks
Heading Hold		Airspeed less than 40 knots or Roll attitude < 3 degrees Roll rate < 3 deg/sec Yaw rate < 1 deg/sec Lateral and directional controls within software dead band	Airspeed greater than 50 knots and any of the following: Roll attitude > 3 deg Roll rate > 3 deg/sec Yaw rate > 1 deg/sec Lateral or directional controls out of software dead band	No turn coordination at low speed. Above 50 knots, AFCS switches between heading hold and turn coordination based on disengagement conditions
Altitude Hold	Radar	Aircraft off the ground and altitude < 1000 ft above ground level	Altitude greater than 1000 ft above ground level or aircraft on the ground	Radar and barometric altitude hold must be selected separately. Radar hold will not reengage when aircraft descends below 1000 ft unless the mode is reselected
	Barometric	Aircraft off the ground and hover assist disengaged	Aircraft on the ground	
Velocity Stability	Longitudinal	Airspeed <42 knots	Airspeed >47 knots	Velocity stability mode disengages at 47 knots, accelerating, and will reengage when decelerating through 42 knots
	Lateral	Airspeed <42 knots Roll attitude <3 degrees Roll rate <1 deg/sec	Airspeed >47 knots or aircraft on the ground	
Hover Assist	Ground Speed Hold	Velocity stability engaged and fore/aft and sideward Ground speeds < 8 knots	Velocity stability disengaged or fore/aft or lateral ground speed > 25 knots or aircraft on the ground	
	Position Hold	Velocity stability engaged and fore/aft and sideward ground speed < 2 knots and longitudinal and lateral controls within software dead band	Velocity stability disengaged or fore/aft or sideward ground speed speed >3.6 knots or longitudinal or lateral control out of software dead band or aircraft on the ground	Position hold will reengage when aircraft is back within constraints if ground speed has not exceeded 25 knots

APPENDIX C. INSTRUMENTATION

1. An airborne data acquisition system was installed. The system included transducers, wiring, signal conditioning, pulse code modulation (PCM) encoder, magnetic tape recorder, and cockpit displays and controls. A telemetry transmitter was also installed to send the PCM encoded data stream to a ground station.

2. Instrumentation and related special equipment installed are presented in the following list.

Evaluation Pilot Station Displays

Pressure altitude
Airspeed
Vertical rate of climb
Main rotor speed
Engine torque (both engines)
Engine measured gas temperature (both engines)
Engine power turbine speed (both engines)
Engine gas generator speed (both engines)
Radar altitude
Normal acceleration (cg)
Primary attitude indicator
Turn needle and ball
Data system controls
Event switch
ADOCS controls and displays

Safety Pilot Station Displays

Pressure altitude
Airspeed
Main rotor speed
Engine Torque (both engines)
Engine measured gas temperature (both engines)
Engine gas generator speed (both engines)
Total air temperature
Time code display
Event switch

Parameters Recorded on Magnetic Tape

Time code
Event
Main rotor speed
Engine torque (both engines)
Engine measured gas temperature (both engines)
Engine gas generator speed (both engines)
Engine power turbine speed (both engines)

- Airspeed
- Longitudinal ground speed
- Lateral ground speed
- Longitudinal ground position
- Lateral ground position
- Pressure altitude
- Total air temperature
- Pilot PFCS commands
    - Longitudinal
    - Lateral
    - Directional
    - Collective
- Aircraft attitudes
    - Pitch
    - Roll
    - Yaw
- Aircraft angular velocities
    - Pitch
    - Roll
    - Yaw
- Radar altitude
- CG normal acceleration
- AFCS commands
    - Longitudinal
    - Lateral
    - Lateral
    - Vertical
- PFCS output
    - Longitudinal
    - Lateral
    - Lateral
    - Vertical
- Flight control processor logic indicators
    - Heading hold engaged
    - Velocity stability engaged
    - Hover assist engaged
    - Altitude hold engaged
    - Main landing gear on the ground
    - Tail landing gear on the ground
    - AFCS engaged (by axis)
        - longitudinal
        - lateral
        - directional
        - vertical
    - Turn coordination on
    - Lateral rate command control laws in use
    - ADOCS engaged

APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

GENERAL

1. This test was conducted to ensure safe operation of the advanced digital/optical control system (ADOCS) throughout the flight envelope. Therefore, the first priority of the test was to ensure that the safety pilot could safely take control of the aircraft in the event of an ADOCS malfunction. Tests were conducted in all flight regimes to ensure that he could. The second priority was to look for any control transients that might be present at switching points in the flight control software. These switching points could be where the selectable modes were engaged/disengaged or where control laws were automatically switched. The third priority of the test was to evaluate the capability of the ADOCS to perform mission tasks. Specific test techniques are discussed in the Results and Discussion section of this report when appropriate.

AIRCRAFT RIGGING

2. The rigging of the main and tail rotors were checked and found to be within the tolerances of the UH-60 maintenance manual.

AIRCRAFT WEIGHT AND BALANCE

3. The aircraft weight and balance were determined by Boeing Vertol (BV) prior to these tests. The aircraft hardware configuration was maintained constant during the test. The engine start gross weight and longitudinal center of gravity were constant during the test (15072 pounds, fuselage station 359.7). No attempt was made to control the gross weight or center of gravity during the test.

MISSION MANEUVERING CHARACTERISTICS

4. The mission maneuvers discussed in the Results and Discussion section were flown to evaluate the capability of the ADOCS to perform mission tasks. In addition, the BV flight plan for user demonstration was evaluated. That flight plan is presented in figures 1 and 2.

HANDLING QUALITIES RATING SCALE

5. Pilot comments concerning the ease of accomplishing mission tasks were quantified using the handling qualities rating scale presented in figure 3.

EVENT	ELAPSED TIME	ARMY FIELD CIRCULAR 1-212 TASK #'s	SELECTABLE MODES					
			CORE	HDG HLD	VEL STAB	RAD HOLD	BAR HOLD	HOVER ASSIST
CRUISE FLIGHT ENGAGEMENT (Introduce control axis one at a time.)			X	X				
MANEUVERING FLIGHT CLIMBS/DESCENTS ACCEL/DECEL TURNS GROUND TRACKING	30 min	1021	X	X				
NOE FLIGHT (Selectable modes as desired)	40 min	1035, 1037, 1038	X	X				
INSTRUMENT APPROACH	55 min	1081	X	X			X	
TRAFFIC PATTERN		1022, 1028	X	X				
NORMAL TAKEOFF		1018	X	X				
MAXIMUM PERFORMANCE TAKEOFF	1hr 5min	1019	X	X				
PRECISION HOVER (Bring on selectable modes one at a time and repeat pedal turns, sideward & rearward flight)	1hr 25min	1017	X	X	X	X		X
MASK/UNMASK (perform several times bringing on selectable modes)		1090	X	X	X	X		X

Figure 1. User Demonstration Flight Plan

EVENT	ELAPSED TIME	ARMY FIELD CIRCULAR 1-212 TASK Ø's	SELECTABLE MODES CORE	HDG HLD	VEL STAB	RAD HOLD	BAR HOLD	HOVER ASSIST
HOVER OGE		1036	X	X	X	X		X
TAKEOFFS & LANDINGS TO INCLUDE SLOPED	1hr 40min	1032	X	X				
GROUND TAXI		1015	X	X				

Figure 2. User Demonstration Flight Plan (Continued)

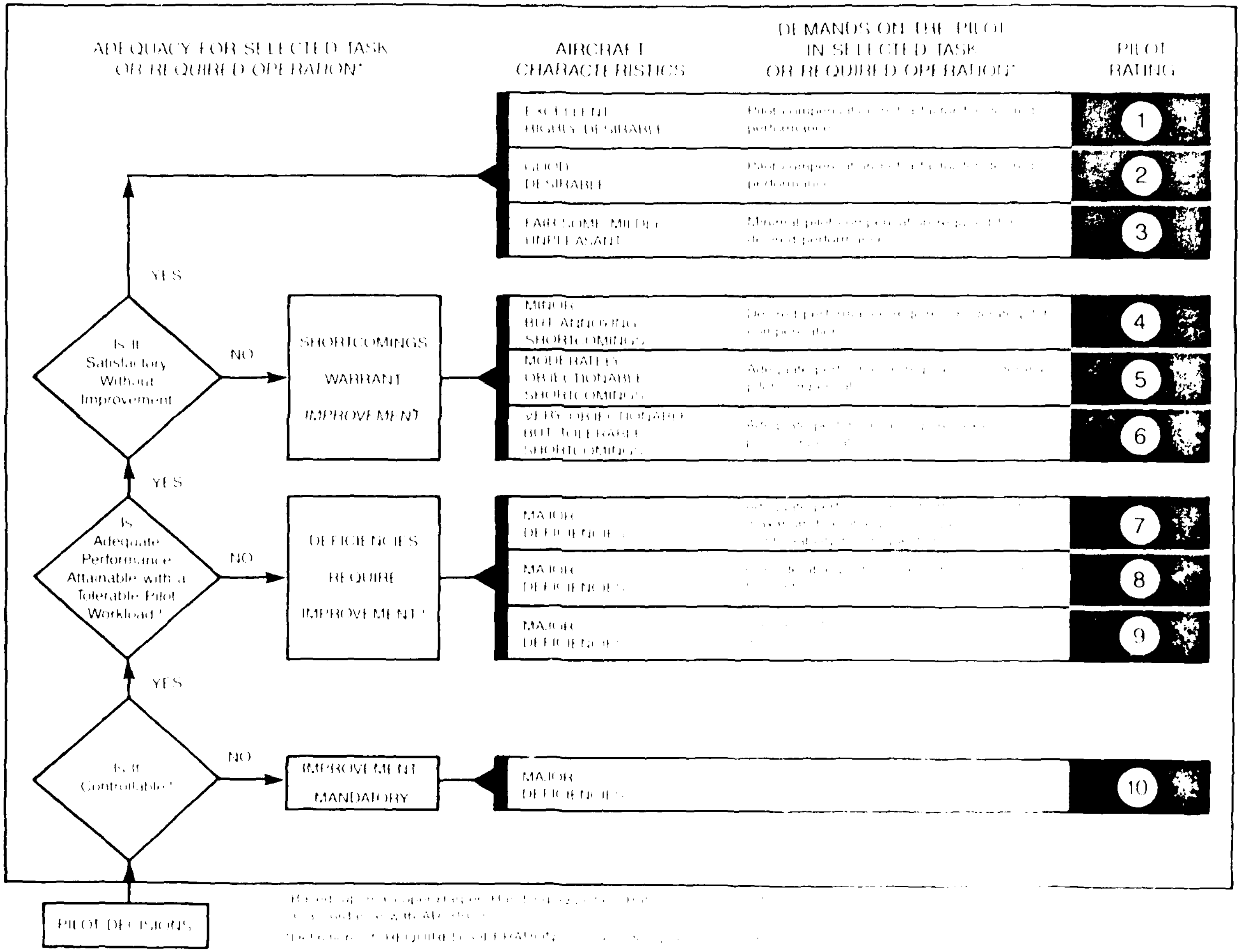


Figure 3. Handling Qualities Rating Scale

APPENDIX E. TEST DATA

INDEX

FIGURE 1

RADAR ALTITUDE HOLD DISENGAGE
UH-60A/ADOCS USA S/N

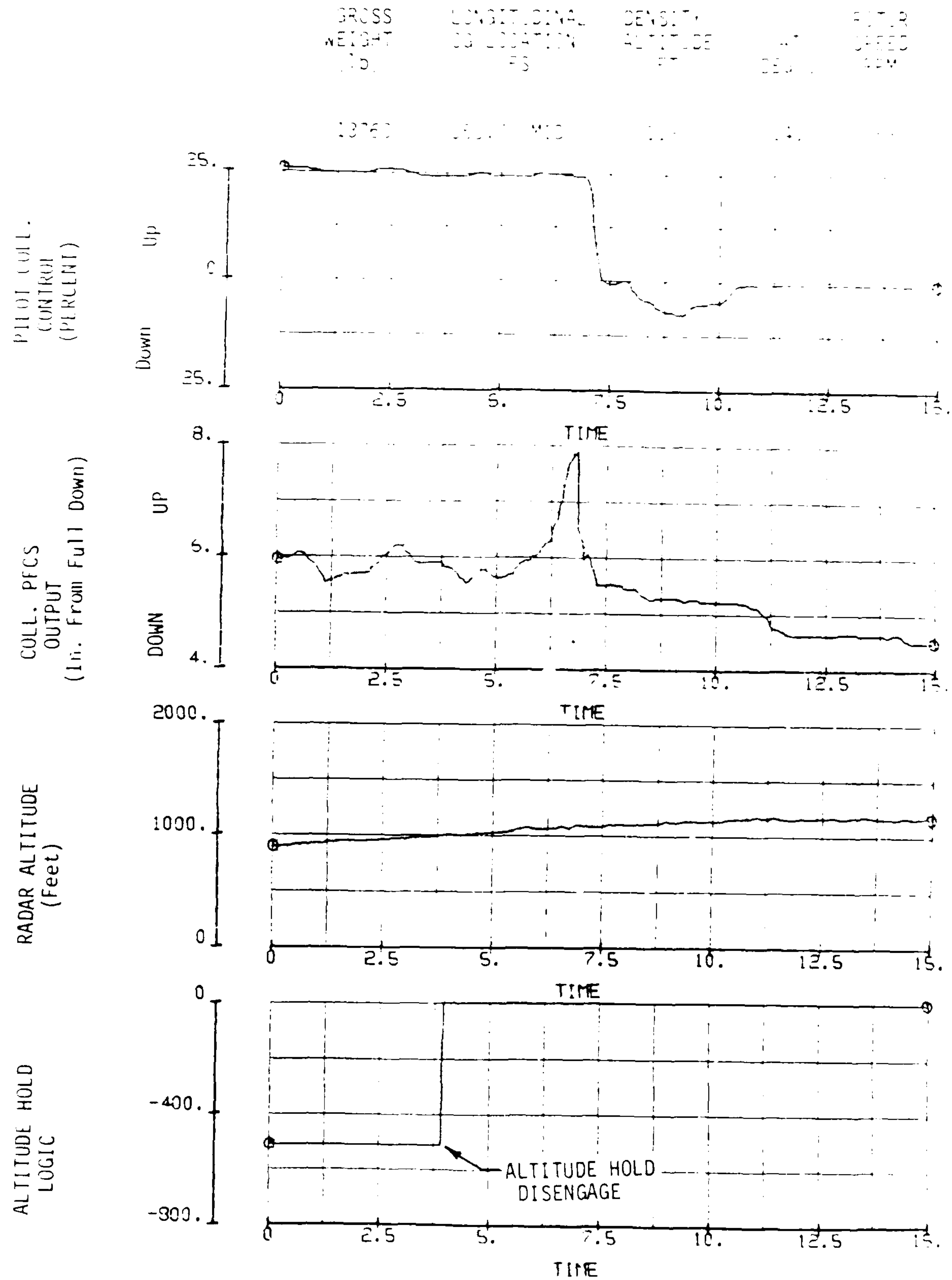


FIGURE 2

BAROMETRIC ALTITUDE HOLD DISENGAGE
JUH-60A/ADOCS USA S/N 79-[illegible]

GROSS WEIGHT (LB)	LONGITUDINAL CG LOCATION (FS)	DENSITY ALTITUDE (FT)	OAT (DEG C)	ROTOR SPEED (RPM)
[illegible]	[illegible] MID	[illegible]	[illegible]	[illegible]

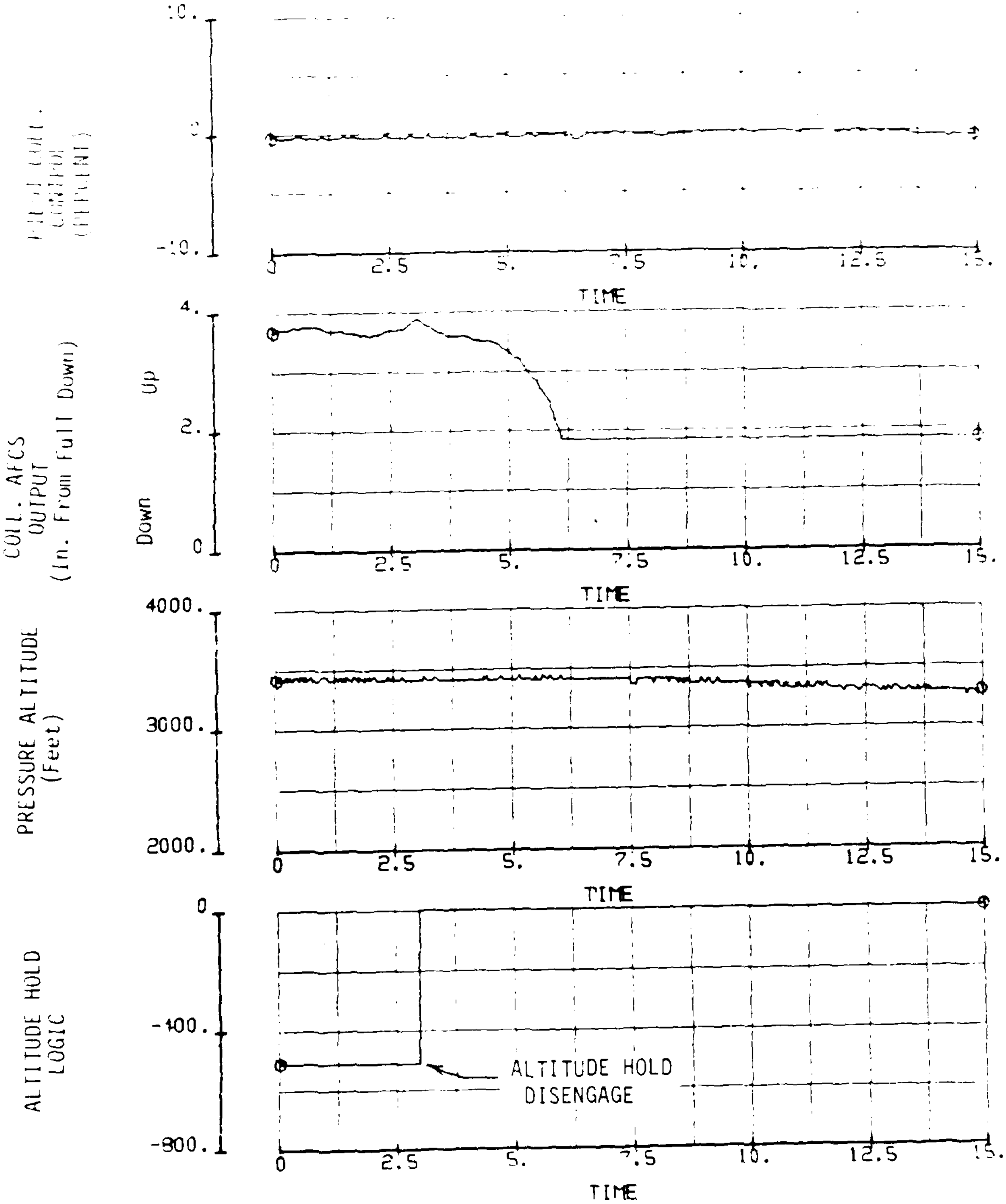


FIGURE 3

VERTICAL LANDING
JUH-60A/ADOCS USA S/N 78-23012

GROSS WEIGHT (lb)	LONGITUDINAL CG LOCATION (FS)	DENSITY ALTITUDE (FT)	OAT DEG C	ROTOR SPEED (RPM)
14310	356.3 MID	[illegible]	[illegible]	[illegible]

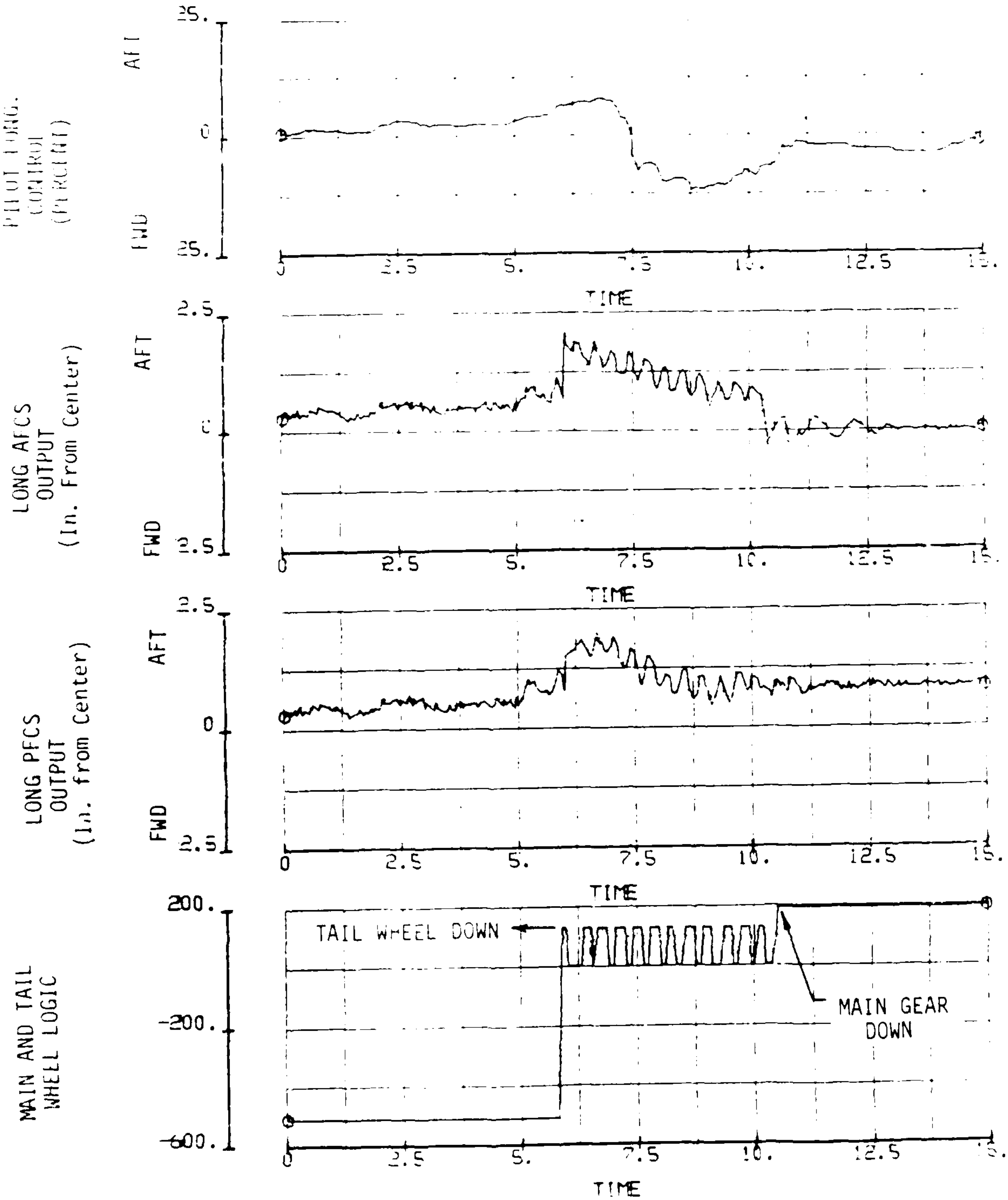


FIGURE 4

TAKEOFF FROM 5° NOSE UP SLOPE
JUH-60A/ADOCS USA S/N 78-23012

GROSS WEIGHT (lb)	LONGITUDINAL CG LOCATION (FS)	DENSITY ALTITUDE (FT)	OAT (DEG C)	ROTOR SPEED (RPM)
14320	356.1 (MID)	-330	11.0	258

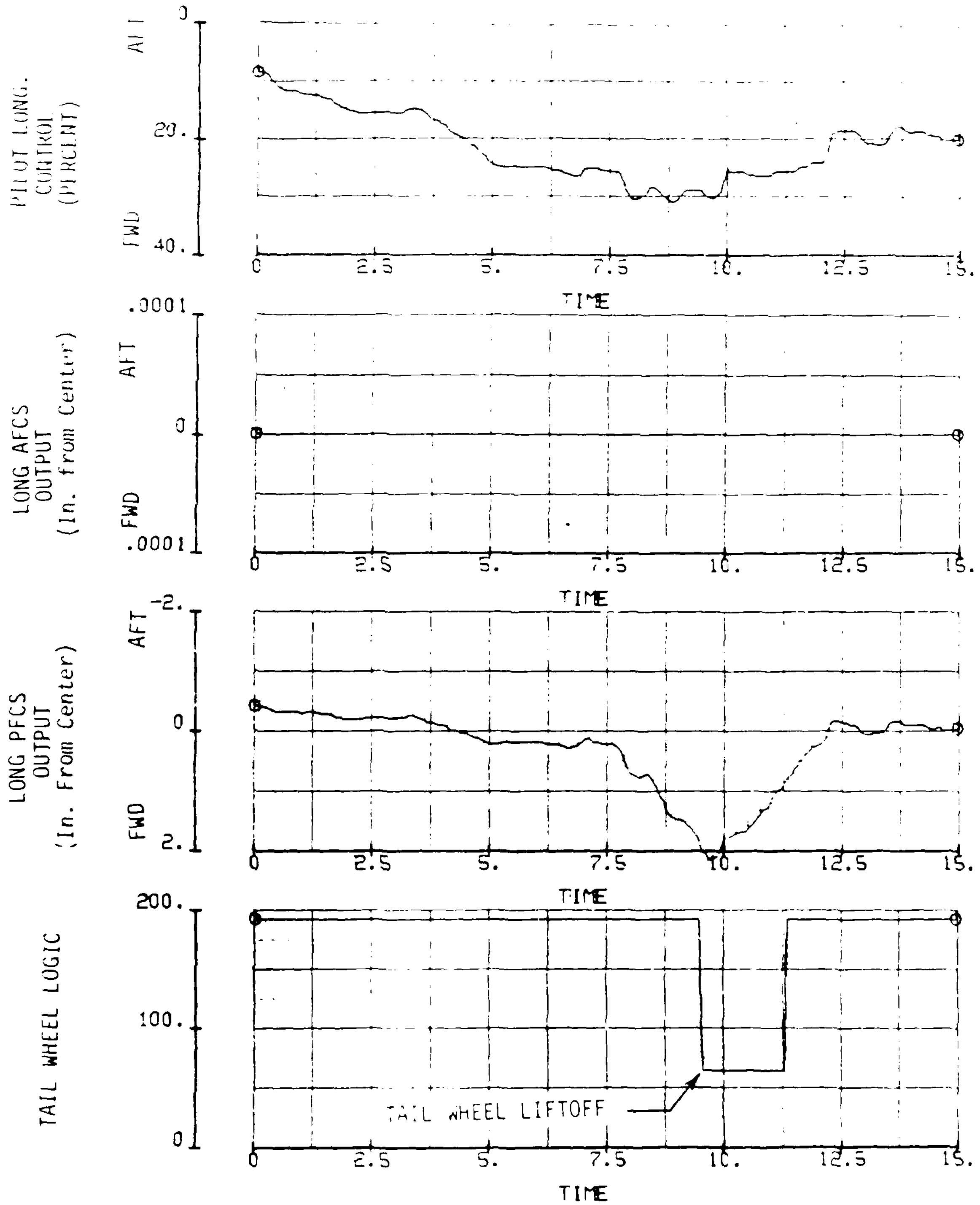


FIGURE 5

HOVER ASSIST DISENGAGE
JUH-60A/ADOCS USA S/N 78-23012

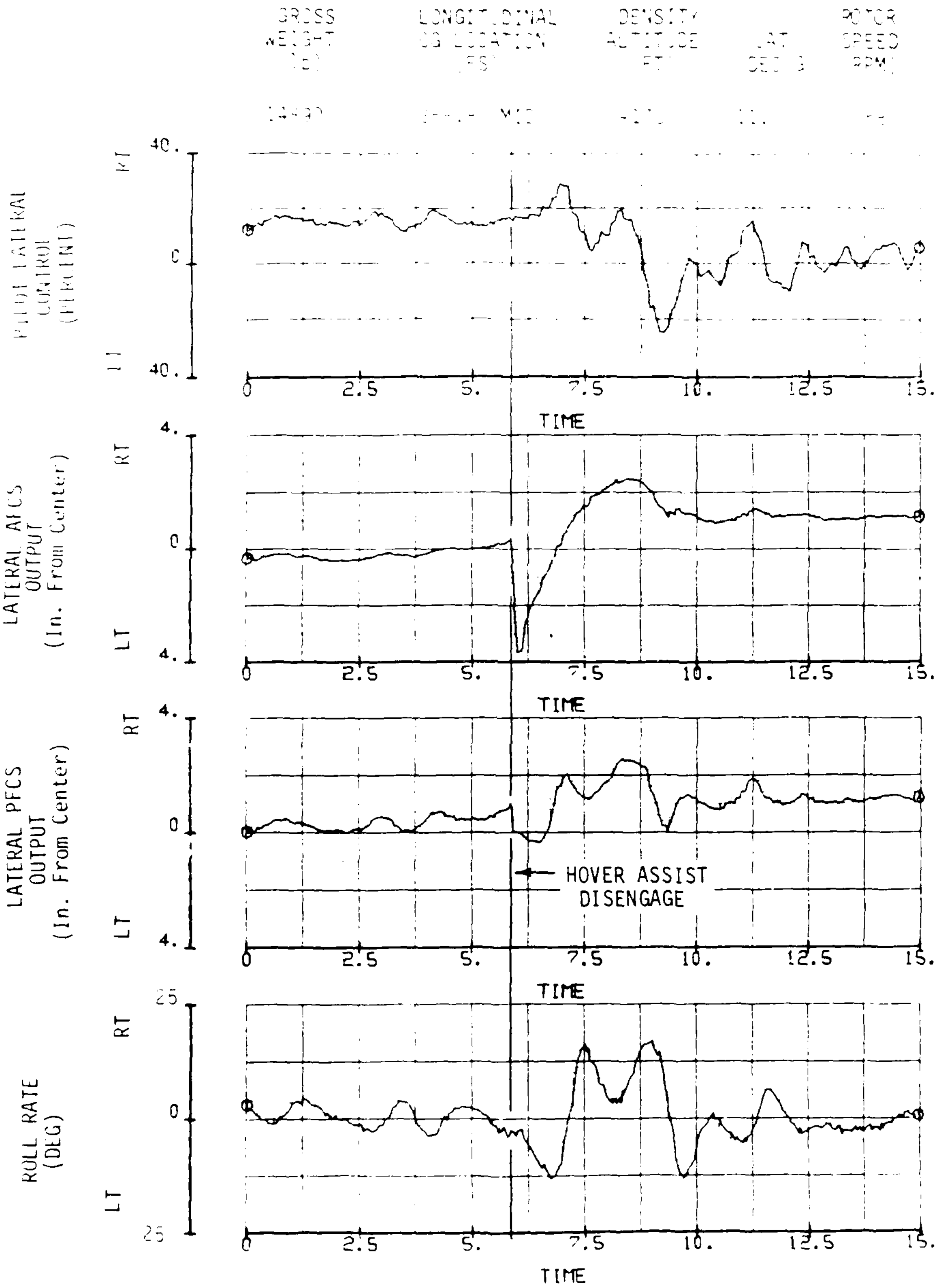
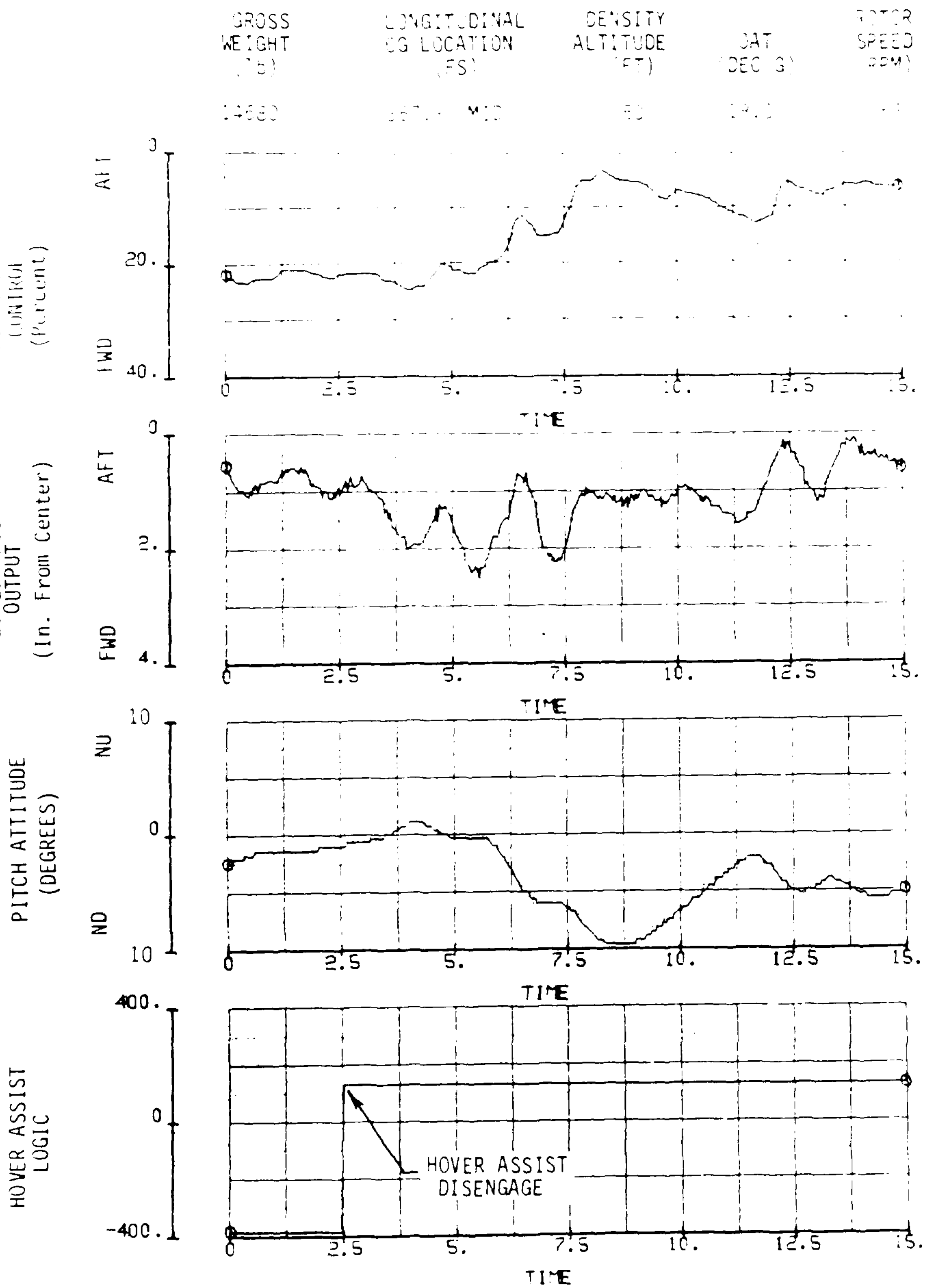


FIGURE 6

HOVER ASSIST DISENGAGE
JUH-60A/ADOCS USA S/N 78-23012



DISTRIBUTION

HQDA (DALO-AV, DALO-FDQ, DAMO-HRS, DAMA-PPM-T, DAMA-RA, DAMA-WSA)	6
US Army Materiel Command (AMCDE-SA, AMCDE-P, AMCCA-SA, AMCCA-ST)	[illegible]
US Army Training and Doctrine Command (ATCD-T, ATCD-B)	2
US Army Aviation Systems Command (AMSAV-E, AMSAV-P, AMSAV-MC, AMSAV-ME, AMSAV-L, AMSAV-N, AMSAV-GTD)	8
US Army Test and Evaluation Command (AMSTE-TE-V, AMSTE-TE-O)	2
US Army Logistics Evaluation Agency (DALO-LEI)	1
US Army Materiel Systems Analysis Agency (AMXSY-RV, AMXSY-MP)	8
US Army Operational Test and Evaluation Agency (CSTE-AVSD-E)	2
US Army Armor School (ATSB-CD-TE)	1
US Army Aviation Center (ATZQ-D-T, ATZQ-CDC-C, ATZQ-TSM-A, ATZQ-TSM-S, ATZQ-TSM-LH)	5
US Army Combined Arms Center (ATZL-TIE)	1
US Army Safety Center (PESC-SPA, PESC-SE)	2
US Army Cost and Economic Analysis Center (CACC-AM)	1
US Army Aviation Research and Technology Activity (AVSCOM) NASA/Ames Research Center (SAVRT-R, SAVRT-M (Library)	3
US Army Aviation Research and Technology Activity (AVSCOM) Aviation Applied Technology Directorate (SAVRT-TY-DRD SAVRT-TY-TSC (Tech Library)	2

US Army Aviation Research and Technology Activity (AVSCOM)	1
Aeroflightdynamics Directorate (SAVRT-AF-D)	
US Army Aviation Research and Technology Activity (AVSCOM)	1
Propulsion Directorate (SAVRT-PN-D)	
Defense Technical Information Center (DTIC)	2
US Military Academy, Department of Mechanics	1
(Aero Group Director)	
ASD/AFXT, ASD/ENF	2
US Army Aviation Development Test Activity (STEBG-CT)	2
Assistant Technical Director for Projects, Code: CT-24	
(Mr. Joseph Dunn)	2
6520 Test Group (ENML)	1
Commander, Naval Air Systems Command (AIR 5115B, AIR 5301)	3
Defense Intelligence Agency (DIA-DT-2D)	1
Headquarters United States Army Aviation Center and	
Fort Rucker (ATZQ-ESO-L)	1
US Army Aviation Systems Command (AMSAV-EA)	1
US Army Aviation Systems Command (AMSAV-EC)	2
US Army Aviation Systems Command (AMSAV-ES)	1
US Army Aviation Systems Command (AMSAV-ED)	2
US Army Aviation Systems Command (AMCPM-BH-T)	2
Director, Aviation Applied Technology Directorate	
(SAVRT-TY-ATA)	4

END
DATE
FILMED
5-88
DTIC